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Contract Number N00014-79-C-0494
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Annual Progress Report

Project Title: Image Processing
Contract Number: N00014-79-C-0494
Task Number: NR 042-422

I. Introduction

This report is organized according to the topics we have worked under this project which include statistical image segmentation, two-dimensional ARMA models, multichannel (multivariate) maximum entropy spectral analysis, and non-Gaussian signal processing, etc. Under each topic, the reports and papers published or presented are also listed. A new AED-512 Imaging/Graphics terminal has been installed in our PDP11/45 minicomputer. The use of the terminal for the image processing project research is also presented.

II. Statistical Image Segmentation

Statistical image segmentation refers to the computer-oriented procedures that partition the image into meaningful parts by using the statistical pattern recognition techniques. A number of techniques have been studied, some of which are supervised while others are unsupervised. A critical evaluation of these techniques has been made. Furthermore we have performed an extensive computer study of the Fisher's linear discriminant method, maximum likelihood estimation and decision-directed method for image segmentation. The experimental results suggest that the supervised techniques are more effective, and that both Fisher's linear discriminant (with properly selected features) and the maximum a posteriori estimation methods perform the best with almost equal amounts of computational requirements.

The maximum a posteriori estimation method is potentially superior to other statistical image segmentation techniques in that it is more robust and can be extended to the more general Markov random fields than the Markov chain as assumed in our study. This problem is being further studied. The Fisher's linear discriminant method requires careful selection of features such that the pattern classes are as close to linearly separable as possible. We are now examining various feature selection procedures for the use of image segmentation.

List of Reports:

1. "Two experiments on statistical image segmentation," Technical Report, SMU-EE-TR-80-9, Sept. 15, 1980.
2. "On the use of Fisher's linear discriminant for image segmentation," Technical Report, SMU-EE-TR-80-10, Nov. 3, 1980.
3. "A comparative evaluation of statistical image segmentation techniques," Technical Report, SMU-EE-TR-81-3, Jan. 26, 1981. To be presented at the 1981 Joint Statistical Meetings.
4. "Some experimental results on linear estimation for image analysis," Technical Report, SMU-EE-TR-81-4, Jan. 28, 1981.

III. Two-Dimensional ARMA Models

The rich contextual information in digital images can be properly described statistically by using two-dimensional ARMA modelling. The models are suitable for noise filtering, image segmentation, classification and encoding. By using the state-space formulation and a second-order two-dimensional ARMA model which is causal, we have developed a computationally efficient procedure that minimizes

recursively the final prediction error for the parameter estimation. The computational requirement of our procedure is much less than the technique employed by Katayama. Our procedure provides a better signal-to-noise ratio improvement. Performance comparison is also made with the adaptive Kalman filtering. The Kalman filtering requires less computation time with comparable image enhancement as the ARMA models. The ARMA models however are more suitable for various purposes mentioned earlier while the Kalman filtering is for noise reduction only.

List of Papers:

1. "A comparison of statistical image processing techniques," Proc. of the IEEE Conference on Cybernetics and Society, pp. 557-560, Oct. 1980.
2. "On two-dimensional ARMA models for image analysis," Proc. of the 5th International Conference on Pattern Recognition, pp. 1128-1131, Dec. 1980. (Copy attached)

IV. Multichannel (Multivariate) Maximum Entropy Spectral Analysis

After developing a high-resolution maximum entropy spectral analysis method originally proposed by Fougere, we have carefully examined the existing methods of the multichannel (multivariate) maximum entropy spectral analysis. New computer algo-rithms are developed for the purpose of image segmentation. Although preliminary result on image segmentation using maximum entropy methods is far from desired, the vector model suggested by the method of analysis is very significant for effective contextual analysis of images. Further study on this subject is much needed.

List of Paper and Report:

1. "Spectral resolution of Fougere's maximum entropy spectral analysis," Proc. of the IEEE, May 1981.
2. "On multichannel (multivariate) maximum entropy spectral analysis," Technical Report, SMU-EE-TR-81-2, Jan. 23, 1981.

V. Non-Gaussian Signal Processing

Extensive survey was made on the literatures in the non-Gaussian signal processing. Problem areas are defined. Particular emphasis is placed on the non-linear adaptive detection procedures for transient signals. Further study is much needed.

List of Papers and Reports:

1. "Learning in statistical pattern recognition," Proc. of the IEEE Conference on Cybernetics and Society, pp. 924-929, Oct. 1980.
2. "Adaptive and learning algorithms for intrusion-detection with seismic sensor data," presented at the Workshop on Digital Signal and Waveform Analysis, Miami Beach, FL, Dec. 1980.
3. "Study of a class of non-Gaussian signal processing problems," Technical Report, SMU-EE-TR-80-6, Aug. 12, 1980.
4. "A bibliography on non-Gaussian signal processing: 1971-1980," Technical Report, SMU-EE-TR-80-8, Aug. 20, 1980.
5. "Geophysical signal recognition," Technical Report, SMU-EE-TR-81-5, Jan. 29, 1981.

VI. Use of Local Statistics

Assumption of stationary processes for an image is not valid in practice. A more reasonable assumption is local stationarity. Thus local statistics can be estimated and utilized for noise

filtering. By modifying a procedure proposed by J. S. Lee, we have developed a new method that provides a better moise filtering in the presence of multiplicative noise using local statistics. For a combined multiplicative and additive noises, the improvement so far is less than desirable. The adaptive digital filtering method that employs local statistics is also examined for noise filtering. It is shown that periodic noises can be considerably removed. Further study is needed to make effective use of local statistics for the removal of various noises.

VII. New Image Terminal

The new AED 512 Imaging/Graphics terminal provides a display of 16 levels of one picture by using 16 different colors. This is a very significant improvement over the two-level display available so far with the Tektronix 4010 terminal. The speed of image display is considerably improved because of the direct memory access interface. We are happy to conclude that the improved display capability offered by the AED terminal will greatly improve the image data manipulation needed for the project.

ON TWO-DIMENSIONAL ARMA MODELS FOR IMAGE ANALYSIS

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The two-dimensional autoregressive moving-average (2-D ARMA) models have been useful for image coding and compression, statistical image modeling, image feature extraction and segmentation, texture characterization, and image restoration and enhancement. This paper provides a critical review of the 2-D ARMA models for image analysis. Particular emphasis is placed on restoration of noisy images using 2-D ARMA models. Computer results are presented for comparative evaluation study. Problem areas such as order determination are examined. Although there are shortcomings and unsolved problems it is concluded that the models are very effective linear models for image analysis.

I. Introduction

The 2-D ARMA models are now playing an increasingly important role in image analysis just as the linear prediction is important in speech signal processing. The primary advantage of the models is the good linear approximation to real data. For one-dimensional data, the models are now well developed. Extension of the one-dimensional to two-dimensional models is not straightforward however. In fact much work remains to be done on 2-D ARMA models for image analysis. For examples, efficient procedures to determine the coefficients (or parameters) of the two-dimensional autoregressive (AR), moving average, ARMA processes are much needed. The window size or the order determination is another problem which does not yet have a good solution. The models are very suitable for homogeneous random field. The simplicity of linear model however outweighs the shortcomings and problems mentioned above. The references at the end of this paper provide a list of recent publications in this area.

II. Applications of 2-D ARMA Models to Image Analysis

Let x_{rs} be the gray level of the picture element at rth row and sth column of a digitized picture. For the nth order autoregressive model, the picture elements up to a distance of n should be included in the model. The general expression for non-causal models is given by:

$$x_{rs} = \sum_{i=1}^{n} a_i(x_{r-1,s} + x_{r+1,s}) + \sum_{i=1}^{n} b_i(x_{r,s-1} + x_{r,s+1}) + w_{rs} \qquad (1)$$

where w_{rs} is a zero mean input Gaussian sequence with finite variance which may or may not be known. For causal models, only past history terms should be included in Eq. (1). The parameters a_i and b_i can be estimated by using the principle of minimum mean square error estimation if the causal model is considered. For the ARMA models, w_{rs} should be augmented by a set of terms corresponding to the past input sequence.

In image coding and data compression [8,9,11], the estimated parameter values of a_i and b_i along with the initial conditions can be used for image transmission. This represents a very significant data reduction over the use of original image data. The parameters and initial conditions can be coded with established coding schemes. Good quality regenerated picture is availalbe from a second order AR model for Gauss-Markov field [9].

In statistical image modeling, ARMA models take into account the contextural information, from nearest neighbors [1,2,3,5,12,16,21]. In the first order AR model, for example, one of the parameters is for the inter-pixel correlation. Even though the images are rich in contextual information, most dependence is from neighboring pixels (picture elements). Thus low order ARMA models can still be effective to represent the image. The limitation to the study of causal or semi-causal models is a drawback as each pixel should depend on its neighbors in all directions. For modeling of an object-plus-background scene, an adaptive procedure is needed so that the estimated parameters will be adjusted near object boundaries.

In image feature extraction and classification, the parameters of the ARMA models are not very suitable as features for image classification because the joint probability density of the parameters is unknown. A conditional probability density of the gray levels of picture elements under consideration can be determined from estimated parameters and the known distribution of w_{rs} [16]. However, the number of pixels considered is necessarily large and it is not convenient to work with a very high dimensional space. For example, a dimension of 25 is large for a small 5 x 5 subimage.

In image segementation, subimages of similar statistical characteristics tend to have similar ARMA models. The models can be useful to determine region merging in the segmentation process. In model building for pictorial textures, appropriate

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ARMA model can be identified [20] by least square estimation by minimizing the sum of squared residuals. For texture synthesis, a noise generator is used to generate an array of noise from which a new array of data x_{rs} is computed according to the statistical model. The ARMA models appear to be particularly suitable for pictorial textures study [7, 14,19,20].

In restoration or enhancement from noisy images, the estimated parameters of the ARMA model are useful to reconstruct the original image and thus performing effective filtering operations [6,10,13,15, 17,18]. Significant improvement in signal-to-noise ratio is available even for the first order models [6].

III. On a 2-D ARMA Model for Noise Filtering

The model considered here is based on that of Katayama [13]. Assume a 2-D homogeneous image with the autocovariance function,

$$R_{xx}(i,j) = \sigma_x^2 \exp\{-C_1|i| - C_2|j|\};\ C_1,C_2 > 0 \quad (2)$$

The image field with this autocovariance function can be modeled by

$$x_{r+1,s+1} = a_1 x_{r,s+1} + a_2 x_{r+1,s} - a_1 a_2 x_{r,s} + w_{r,s} \quad (3)$$

where $w_{r,s}$ is a Gaussian white noise field with zero mean and variance q.

$$a_1 = \exp(-C_1),\ a_2 = \exp(-C_2),\ q = \sigma_x^2(1-a_1^2)(1-a_2^2)$$

Now consider the observable noisy image,

$$Y_{r,s} = X_{r,s} + v_{r,s} \quad (r = 1,2,---,M;\ s=1,2,---,N) \quad (4)$$

where $v_{r,s}$ is a Gaussian white noise field with mean zero and variance σ^2. The model of (3) and (4) forms a state-space model for the noisy images. For the purpose of the parameter identification, form a 2-D ARMA model for the noisy image,

$$\begin{aligned} Y_{r+1,s+1} &= a_1 Y_{r,s+1} + a_2 Y_{r+1,s} - a_1 a_2 Y_{r,s} \\ &+ v_{r+1,s+1} + (K-1)\{a_1 v_{r,s+1} + a_2 v_{r+1,s} \\ &- a_1 a_2 v_{r,s}\} \end{aligned}$$

where K is a stationary gain, $0 < a_1, a_2, K < 1$.

Let $\theta = (a_1, a_2, K)$. Define the sample variance of $v_{r,s}$ as

$$\Lambda(\theta) = \frac{1}{MN} \sum_{r=1}^{M} \sum_{s=1}^{N} v_{r,s}^2$$

We identify the parameters a_1, a_2 and K such that $\Lambda(\theta)$ is minimized. The method of Steepest Decent is used in the optimization process which is far more efficient computationally than the optimization procedure employed in [13].

Figure 1 is an original image (300 x 400) considered along with its histogram. Figures 2 & 3 are two subimages (150 x 150) studied along with their histograms. Figure 4 is a nosiy image corresponding to Figure 2 with SNR = 1.73. Six iterations are performed in each image in the optimization process. Figures 5 & 6 are the results of filtering for different initial conditions. The procedure converges very well for any initial conditions. Figure 7 has the SNR = 0.87 with filtered result given by Figure 8. Figure 9 is the noisy image corresponding to Figure 3 with SNR = 1.73. Figure 10 is the filtered result. Figure 11 has SNR = 0.87 with filtered result given by Figure 12. All filtered results accompanied by the histograms of the filtered images clearly illustrate that the 2-D ARMA model provides a very effective filtering procedure for the noisy images.

IV. The Order Determination Problem

Although, the Akaike information criterion can be used to determine the window size or model order in horizontal and vertical directions separately [5], maximum likelihood decision rule has been suggested for choice of neighbors. For the subimage of Figure 2, we have employed the procedure developed by Penm and Kanefsky [15] to determine the order accurately. The idea is to examine the determinant of the matrix of sample correlation functions defined by

$$C_{r,s} = \frac{1}{(M-r)(N-s)} \sum_{i=r+1}^{M} \sum_{j=s+1}^{N} x_{i,j}\, x_{i-r,j-s} \quad (5)$$

where $X_{i,j}$ is an element of the data in a window of size M x N. The values of M and N are increased until the determinant falls below certain specified value. The largest M and N values correspond to the window sizes in horizontal and vertical directions respectively. The result of the computation shows that the order should be one in each direction. Thus the ARMA model should have an order of 2 which shows that the assumption of the second order model in the previous section is indeed valid.

V. Concluding Remarks

In this paper we have examined critically the feasibility of 2-D ARMA models for various image analysis studies. On the whole the models are very effective though they do not necessarily perform the best. More research is much needed on the 2-D ARMA models so that the models can serve as a general purpose image analysis tool which is fairly independent of the specific image application under consideration.

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Fig. 1a

Fig. 1b

Fig. 2a

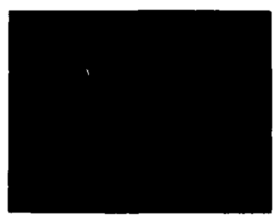

Fig. 2b


Fig. 3a

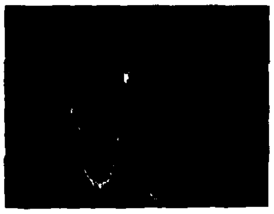
Fig. 3b


Fig. 4a

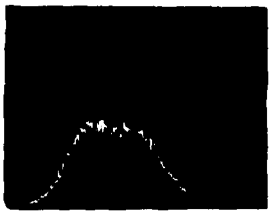
Fig. 4b


Fig. 5a


Fig. 5b

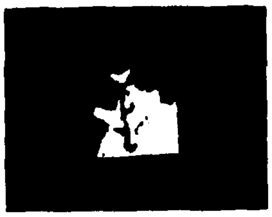
Fig. 6a


Fig. 6b


Fig. 7a


Fig. 7b


Fig. 8a


Fig. 8b


Fig. 9a

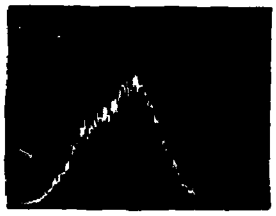
Fig. 9b


Fig. 10a


Fig. 10b


Fig. 11a

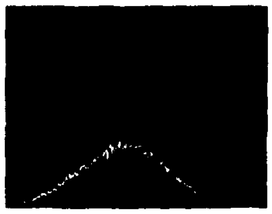
Fig. 11b


Fig. 12a


Fig. 12b

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SMU-EE-TR-81-1, Jan. 19, 1981
"A Bibliography on Maximum Entropy Spectral Analysis and Related Techniques," by C. H. Chen

SMU-EE-TR-81-2, Jan. 23, 1981
"On Multichannel (Multivariate) Maximum Entropy Spectral Analysis," by C. H. Chen and Chihsung Yen

SMU-EE-TR-81-3, Jan. 26, 1981
"A Comparative Evaluation of Statistical Image Segmentation Techniques," by C. H. Chen

SMU-EE-TR-81-4, Jan. 28, 1981
"Some Experimental Results on Linear Estimation for Image Analysis," by C. H. Chen, Rong-Hwang Wu and Chihsung Yen

SMU-EE-TR-81-5, Jan. 29, 1981
"Geophysical Signal Recognition," by C. H. Chen

SMU-EE-TR-81-6, Jan. 30, 1981
"Some Results in Noise Filtering by Use of Local Statistics," by P. F. Yan and P. F. Li

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes progress made on several aspects of statistical image processing research.

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